BELLCOMM, INC.

SUBJECT: Resolution Limit of the 24 Inch Lunar Orbiter Lens with Linear Motion Blur - Case 340

DATE: October 10, 1966

FROM: V. B. Schneider

ABSTRACT

By taking into account the attenuation in high-frequency response due to linear motion blurring, a new resolution limit for the Lunar Orbiter high resolution lens-film system, in the degraded condition of Mission A. is found, It is seen that resolution in the direction of blurring is reduced to (4.72) meters per line pair for a 40 meter linear motion blur, while resolution at right angles to the blur retains its original value of one line pair per meter. Processing to compensate for the blur is recommended where small areas of the moon's surface are to be investigated intensively.

(NASA-CR-153836) RESOLUTION LIMIT OF THE 24 INCH LUNAR ORBITER LENS WITH LINEAR MOTION BLUR - CASE 30 (Bellcomm, Inc.) 7 p

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MEMORANDUM FOR FILE

I. INTRODUCTION

Certain of the returned high resolution photographs from the recent Lunar Orbiter mission have linear motion blur due to a camera malfunction. An estimate of this blur, assuming a 1/50 second shutter speed and no compensation for flight motion, is that it extends 40 meters in length. Several methods of image restoration for these blurred photographs are presently under study. Before undertaking to apply any of these methods, it is of interest to know what resolution limit can be expected from an optimal processing of the photographs. As will be seen the resolution limit is degraded from the specified performance of 1m at 46 km altitude to not better than 5 m at 46 km.

II. METHODS

For a given blurred photograph, we can construct an x-y coordinate system with the x-axis in the direction of blur. The illumination of the photograph is then a function of the coordinates. Holding y constant (corresponding to scanning in the x direction), the illumination of the photograph is given by S(x). The original, unblurred signal is denoted by s(x), and the relation between the two signals can be found in terms of their Fourier transforms:

$$S(f) = \left(\frac{1 - e^{-j2\pi fc}}{j2\pi fc}\right) s(f) \qquad (1)$$

or

$$\left| S(f) \right| = \left(\frac{\sin(\pi fc)}{\pi fc}\right) s(f) \qquad (1,a)$$

Here, c is the width of the blur as seen on the focal plane of the camera. For a 610 mm focal length of the lens (24") and a photograph taken from 46 km altitude.

$$\frac{c}{610} = \frac{40}{46,000} \qquad (2)$$

or

$$c = 0.532 \text{ mm} \qquad (2,a)$$

The frequency f is also measured in the focal plane; the units of f in equation (1) are line pairs/mm.

The first zero of the $\sin(\pi fc)$ term of (1) comes at

$$f = 1/c = 1.88 \text{ line pairs/mm.} \quad (3)$$

Since the signal will be obscured by noise in the vicinity of each zero of the transfer function of equation (1,a), it would seem that the signal cannot be perfectly recovered beyond 1.88 line pairs/mm. However, signal components are recoverable beyond 1.88 line piars/mm. In this paper, we derive an upper frequency bound on the recoverable signal spectrum of the blurred photographs. Because the zeroes of the $\sin(\pi fc)$ term are so closely spaced (intervals of 1.88 cpmm.), we ignore the variations of the $\sin(\pi fc)$ term in equation (1), and include only the effects of the "envelope" of the blur transfer function, the $(1/\pi fc)$ term of equation (1).

The method for finding the resolution limit of an optical system is to compare as a function of spatial frequency the modulation available from the lens-film system with the modulation required to overcome noise.[5] In reference 3, the Lunar Orbiter optical system is calibrated by a MIL-SPEC tri-bar target with 3:1 contrast ratio, corresponding to an object modulation of

$$\frac{3-1}{3+1} = 1/2.$$

The resolution limit is then found to be the intersection of the curve of modulation available from the system and the AIM noise modulation curve. In our example of a lens-film system with linear motion blur, we take the product of the lens modulation transfer function (MTF), the MTF of the SO-243 film used in the Lunar Orbiter camera, and the blur MTF envelope term just mentioned. The resultant MTF is multiplied by a scale factor of 1/2 to yield the modulation available from the system as a function of spatial frequency when the target is a tri-bar target with modulation of 1/2.

The modulation required to overcome niose as a function of spatial frequency* is given in reference 4 as:

$$\text{Modulation} = \frac{(0.04\sigma(D))f}{\gamma} \quad (4)$$

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*Equation (4) represents the image modulation required to overcome noise for a MIL-SPEC tri-bar target. It corresponds to the AIM subjective detection curve at high frequencies, but the AIM curve becomes asymptotic to a modulation of .04 at low frequencies, this being the minimum modulation required for human perception in the absence of noise. This threshold is irrelevant to the problem of processing pictures mechanically.

Here, $\sigma(D)$ = (R.M.S. granularity) x 10^3 obtained with a 24 micron scanning aperture

= (2 x σ_{48} (D)), where $\sigma_{48}(D)$ is the RMS granularity value obtained with a 48 micron scanning aperture at a density D.

γ = Gamma of the processed film

f = Spatial frequency in line pairs/mm

Table I presents the data points that were calculated for the transfer function resulting from the blur, the film MTF, and the MTF of the 24" lens. Figure 1 plots the intersection of the resulting available modulation curve with the granularity noise modulation line. As seen from Figure 1, the limiting frequency is 16 line pairs/mm corresponding to the point where noise and picture are confused. This corresponds to a ground resolution of x_2 meters at 46 km, with

$$x_2 = \frac{4.6 \times 10^4}{6.1 \times 10^2 \times 1.6 \times 10} = 4.72 \text{ meters} \qquad (5)$$

III. CONCLUSIONS

Since the linear motion blur affects resolution in one direction only, it is possible to retrieve information down to 4.72 meters per line pair in the smeared direction and one meter per line pair at right angles to this direction. Since the low resolution photographs only provide information down to 8 meters/line pair, processing of the blurred photographs will yield more detailed information.

Because of problems in complete reconstruction of the affected photographs,* processing of the blurred photographs is to be recommended on a selective basis only, where a particular area of the moon's surface has been singled out for specially detailed scrutiny.

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*V. B. Schneider, work in progress.

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APPENDIX I

SOURCES FOR THE LENS FILM PARAMETERS

Reference 1 provides the MTF of the 24" Lunar Orbiter lens. Reference 2 provides the MTF of the SO-243 film used in the Lunar Orbiter mission. Regarding spectral sensitivity to light of the SO-243, page 2-75 of reference 3 claims that "differences between the Bimat and D-19 process spectral sensitivity are small and can be neglected". On this admittedly tenuous basis, it was assumed that the SO-243 film MTF given in the Kodak Manual for D-19 development is identical with the MTF obtained from the Bimat development. An additional assumption was that the R.M.S. granularity value quoted as 7.4 for SO-243 film developed in D-19 and scanned by a 48 micron aperture device was the same as for SO-243 with the Bimat process. The value of film gamma for SO-243 processed in Bimat was found from interpolation in Figure 2-21 of reference 3. The value thus found for SO-243 film processed in Bimat is 1.5.

REFERENCES

1. LOP Engineering Note L-009038-KU, April 19, 1965, Eastman Kodak

2. Manual of Physical Properties of Kodak Aerial and Special Sensitized Materials, 371-IPS-1200, June, 1966, Eastman Kodak.

3. Photographic Subsystem Reference Handbook for the Lunar Orbiter Program: L-018375-RU, March 15, 1966, Eastman Kodak.

4. The Practical Application of Modulation Transfer Functions, March 6, 1963, Perkin-Elmer Corp.

5. M. D. Roseneau, The Optical Specification of Photographic Viewers. Photogrammetric Engineering (July 1964), 607-610.

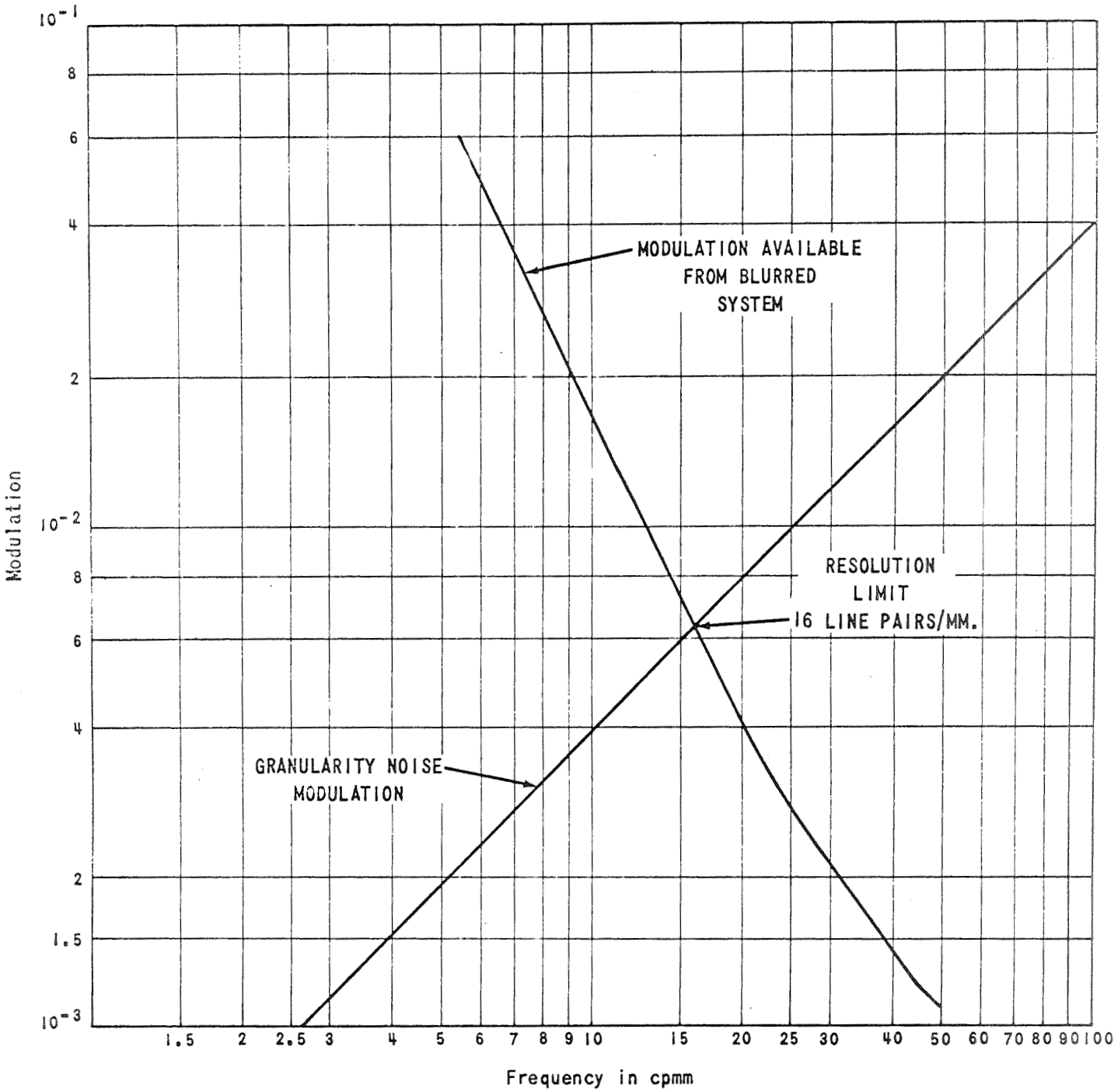

FIGURE 1 - MODULATION OBTAINABLE FROM 24" LUNAR ORBITER LENS, SO-243 FILM, AND 40-METER LINEAR MOTION BLUR SYSTEM. 0.0° ON AXIS, 3:1 CONTRAST RATIO OF TARGET.